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Improvement of obstacle avoidance on a compliant surface during transfer to a novel visual task after variable practice under unusual visual conditions'[1]

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Summary

Previous work has shown that variable practice facilitates adaptation to novel visuomotor changes during throwing tasks and during obstacle avoidance on a solid floor. We asked if locomotor skill on an obstacle avoidance task on a compliant surface, and in a novel visuomotor environment, improved through training with variable practice on visuomotor changes. 61 normal adults practiced traversing the obstacle course; half the trials were done without visual changes, half the trials were done while wearing either sham or visual distortion lenses in single lens or multiple lens groups. Transfer tests on the obstacle course while wearing novel lenses showed significantly better scores with multiple lenses than sham; the single lens group did not differ from sham or multiple lens groups. Thus, performance in a novel visual environment, on a compliant surface improves most with variable practice training.

Exposure to multiple visuomotor transformations during training may facilitate motor learning in response to visuomotor change. Roller, Cohen, Kimball and Bloomberg (2001) trained participants to throw balls during quiet standing while they wore visual distortion lenses and then tested them while they wore novel visual distortion lenses. Cohen, Bloomberg and Mulavara (2005) trained subjects to perform eye-hand and eye-foot coordination tasks while they wore visual distortion lenses and then tested them on a simple obstacle course on a solid floor. while they wore novel visual distortion lenses. In both cases the group exposed to several different types of visual distortion lenses during training performed significantly better than the group trained with sham lenses. Learned motor skills may generalize to some novel visuomotor transformations (Seidler, 2004; Abeele & Bock, 2001; Stroud, Harm & Klaus, 2005), to obstacle avoidance under different treadmill walking conditions (Lam & Dietz, 2004) and from walking to reaching (Morton & Bastian, 2004). Thus, performers who practice solving a class of motor problems may improve their ability to adapt to novel sensorimotor conditions with similar but not identical task requirements. Hence, they may learn to generalize better than performers who practice generating only one solution by training under invariant conditions (Bernstein 1967; Bock, Schneider & Bloomberg, 2001; Kennedy, Berbaum,

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Williams, Brannan & Welch, 1987; Kerr & Booth 1978; Shea & Kohl 1990; Welch, Bridgeman, Anand, & Browman, 1993).

We are interested in the application of these principles to actual training scenarios. Our populations of interest include patients with health conditions that cause balance problems and healthy, post-flight astronauts with balance impairments due to exposure to microgravity. No previous studies have tested the use of an adaptive generalization paradigm to facilitate motor learning when balance is perturbed on the support surface. The present experiment examined the use of adaptive generalization on a more complex locomotor task on an unstable surface, to test the hypothesis that variable lens training would lead to better performance on the transfer and retention tests than training with a single or sham lens. Positive findings to support our hypothesis would support the use of pre-flight or in-flight sensorimotor adaptation training for astronauts and it would support the use of variable practice sensorimotor training for balance-impaired patients. The use of two trials per test was designed to test the hypothesis that subjects learn this task over trials. If correct, then functional mobility tests in the clinical or post-flight operational environment should rely on the first trial to give a true picture of the individual's ability to function when faced with a novel balance challenge.

Method

Participants

The 61 participants (31 females, 30 males, mean age 26.3 yrs, S.D. 5) were normal adults with no history of otologic, neurologic, or orthopedic disorders, recruited from among the staff and students at the Texas Medical Center. Participants who wore corrective lenses had at least 20/40 vision when wearing them; they wore their corrective lenses during training and testing.

Materials

Participants wore lenses set in lightweight, black, plastic, safety goggles that accommodated eyeglasses but eliminated peripheral vision. Five pairs of goggles were used: clear plastic with no special optical properties (sham), × 2.0 magnifying, × 0.5 reducing, up/down reversing, and 20° shift right lenses.

All tests involved the Functional Mobility Test (FMT), using an obstacle course in a 5.5 × 6.7 m room. (See Fig. 1.) The base of the course was 10 cm thick, medium density foam (Sunmate foam with skin-soft coating, Dynamic Systems, Inc., Leicester, NC). The compliant foam changes continually as the individual stands on it, making the support surface unreliable and thus more challenging. Eight pairs of bop bags (colorful, inflated, polyethylene, sand-weighted pylons, 0.9 to 1.4 m high, 0.3 m diameter) were placed atop the foam. On two side of the course were two portals, each portal made of a pleated fabric curtain suspended from the ceiling (bottom 1.5 m from the floor) over a pair of Styrofoam blocks (96.5 cm (height) × 40.6 cm (width) × 10.2 cm (thickness) per block.

Procedure

Participants were randomized to one of three lens training groups: sham, single lens (magnifying) and multiple lens (magnifying, reducing, and up/down lenses in each session using a counterbalanced schedule to eliminate possible order effects). Transfer and retention tests used the right shift lenses. On all trials participants were instructed to walk through the obstacle course as rapidly as possibly without touching any obstacles. Dependent measures were the time to walk through the course (time) and the number of obstacles touched (obstacles).

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Two pre-test trials without lenses were performed on the FMT. (A trial was one round walking through the obstacle course.) Two to four days after the last training session participants performed two post-test trials without lenses and then two transfer trials while wearing the right shift lenses. Two weeks after the date of the post- and transfer tests participants performed two follow-up trials without lenses and then two retention trials while wearing the shift-right lenses. Technicians who were blinded to participants' group assignments administered all tests. Inter-rater reliability between 2 raters was calculated using 10 individuals who did not otherwise participate in the study. Pearson product moment correlations were: time, $r = 0.98$, $p < 0.0001$; number of obstacles touched, $r = 0.9$, $p < 0.001$.

In each of the four training sessions, over two weeks with sessions separated by at least 30 hours, participants had 6 trials. On Trials 1, 3 and 5 participants wore goggles. On Trials 2, 4 and 6 participants did not wear goggles. Intervals of non-distorted vision were used in an effort to consolidate motor learning responses to facilitate skill acquisition (Martin, Keating, Goodkin, Bastian & Thach. 1996, Seidler 2004).

This experiment was approved by the Institutional Review Board for Human Subject Research for Baylor College of Medicine and Affiliated Hospitals. Participants gave informed consent prior to participation.

Results

At the pre- and post-test dates the sample size was 61. At the follow-up test the sample size was 35. Some participants dropped out due to scheduling problems.

To look for an effect of practice with the groups collapsed, paired t-tests compared trials 1 and 2 at each set of tests at each test date. For obstacles no significant differences were found between test pairs at the pre- ($t=(60)=0.14$ $p=0.9$), post- ($t(60)=0.7$, $p=0.5$) or follow-up test ($t(34)=0$, no p-value), i.e. trials when lenses were not worn. For time pre-test trial 1 took significantly longer than trial 2, ($t(60)=2.9$, $p=0.005$) but at the post-test ($t(60)=.64$, $p=0.5$) and follow-up test ($t(34)=1.1$, $p=0.2$) trials 1 and 2 did not differ significantly. Obstacles were significantly greater at trial 1 than trial 2 at the transfer test ($t(60)=3.3$, $p=0.002$) but not at the retention test ($t(34)=-1.1$, $p=0.3$). Time was significantly greater at trial 1 than trial 2 at the transfer test ($t(60)=3.5$, $p<0.0008$) and at the retention test ($t(34)=6.9$, $p< 0.01$). Therefore, since the second trial may have yielded a practice effect on trials when lenses were worn, subsequent analyses used only data from Trial 1. See Tables 1 and 2.

Repeated measures analysis of variance (ANOVA) of Trial 1 pre-, post- and follow-up test scores by obstacles was significant for test dates ($F(2, 32)=6.1$, $p=0.004$) but not for the Date by Group interaction ($F(2, 4, 64)=1.6$, $p=0.2$). Post-hoc Bonferroni-corrected t-tests showed significantly fewer obstacles at post- than pre-test ($t(60)=2.6$, $p=0.01$) and fewer obstacles at the pre- than follow-up test ($t(34)=3.6$, $p=0.001$). Post-hoc Bonferroni-corrected t-tests of the difference between post- and follow-up tests were not significant. These data suggested a learning effect over test dates in trials without lenses. ANOVA of trial 1 pre-, post- and follow-up tests scores by time was significant for test dates ($F(2,32)=4.0$, $p=0.02$) and for the Date by Group interaction ($F(2, 4, 64)=3.3$, $p=0.02$). Post-hoc Bonferroni-corrected t-tests showed slightly but significantly shorter times at the post- than the pre-test ($t(60)=3.0$, $p=0.003$), also suggesting a slight learning effect. No other differences were found between test dates with groups collapsed. These findings supported our hypothesis about repeated testing.

ANOVA showed no significant differences among groups at the pre-test for time ($F(2, 57)=2.5$, $p=0.1$) or obstacles ($F(2, 57)=0.1$, $p=0.9$), at the post-test for time ($F(2, 57)=2.8$, $p=0.7$), or at the follow-up test for time ($F(2, 57)=2.2$, $p=0.1$) or obstacles ($F(2, 57)=0.5$, $p=0.6$). The ANOVA at the post-test was significant for obstacles ($F(2, 57)=4.1$, $p=0.3$). Post-hoc Fisher

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Least Significant Difference (FLSD) tests showed a significant difference between the sham and single lens groups (p=0.009), indicating that the single lens group hit significantly fewer obstacles than the sham group. No other differences were found for tests performed without lenses. See Tables 1 and 2.

ANOVA by group, was not significant for time at either the transfer test (F(2)=1.0, p=0.4) or the retention test (F(2)=0.8, p=0.4. ANOVA by group for obstacles at the transfer test was significant (F (2) = 4.5, p=0.02). The significant post-hoc FLSD showed that the multiple lens group touched significantly fewer obstacles than the sham group (p< 0.02). At the retention test, the ANOVA was nonsignificant (F(2)=2.6, p=0.08). See Tables 1 and 2.

Discussion

The results support our hypothesis of a learning effect over trials. This finding has some practice implications for clinical testing. Patients are sometimes given a second trial on clinical balance tests if they have difficulty on the first trial. The finding of a learning effect over trials suggests that the result on subsequent trials may not indicate the patient's ability to respond to a new motor challenge that she might encounter in the community but instead might indicate the patient's ability to learn a motor skill over trials.

The results partially support our hypothesis about training with lenses. Multiple lens practice was more effective than sham training for adapting to a novel visual condition on the transfer trials. Single lens practice did not differ from sham or multiple lens training. The failure to find a difference with the single lens group might have been due to the variability of the data. The failure to find any differences at the retention tests might be have been due to the reduced sample size. Alternatively, since this task was relatively easy and well practiced, once subjects learned the task they may have been able to practice is mentally to improve or maintain performance. Although the finding is weaker than expected it still corroborates our previous work showing that multiple lens practice was better than sham lens practice for ball throwing at a target, walking through a different obstacle course, or training on a treadmill (Roller et al. 2001; Cohen et al. 2005, Mulavara et al in press).

As in our previous study (Cohen et al. 2005), the finding of differences in obstacles but not time probably indicates the speed-accuracy trade-off. Walking slowly would have allowed participants to avoid the obstacles, particularly on the first trial while they learned to interpret visual information through the shift-right lenses.. The lack of differences on time suggests that most participants optimized time at the expense of obstacles. Participants who had not adapted well still seemed to focus on time at the expense of obstacles. Indeed, some participants asked if they were faster than others. We were not surprised by this comment from participants who were medical students, who tend to be competitive, and who were interested in whether or not they were faster than their peers. A less competitive test group might have had different results.

The use of variable practice with lenses apparently gave participants an adaptive advantage only for adapting to novel lenses, but not for performance with normal vision. The finding that participants bumped fewer obstacles and moved through the course faster without lenses at the pre-, post- and follow-up tests was not surprising. On those tests they used normal, unadapted vision. Time did not differ significantly between pre-and follow-up tests. The decrease in obstacles from pre- to follow-up tests was probably an effect of practice, not lens training group.

These findings have some practical application. In many situations, the conditions of practice training cannot replicate exactly the conditions of actual performance. The present results support previous findings that when the critical features for training and testing differ, variability on some parameter during training, e.g. conditions of visibility, may improve

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performance on the criterion task. The present findings extend that idea to locomotion on a unique support surface. Thus, astronauts who will be expected to walk on the Moon or Mars should be exposed to some variations in sensory inputs during training, e.g. egressing the vehicle at a landing site, to facilitate safety and efficiency. Community-dwelling patients with balance problems should be trained to cope with variations in lighting and in the support surfaces – in footwear and also in flooring.

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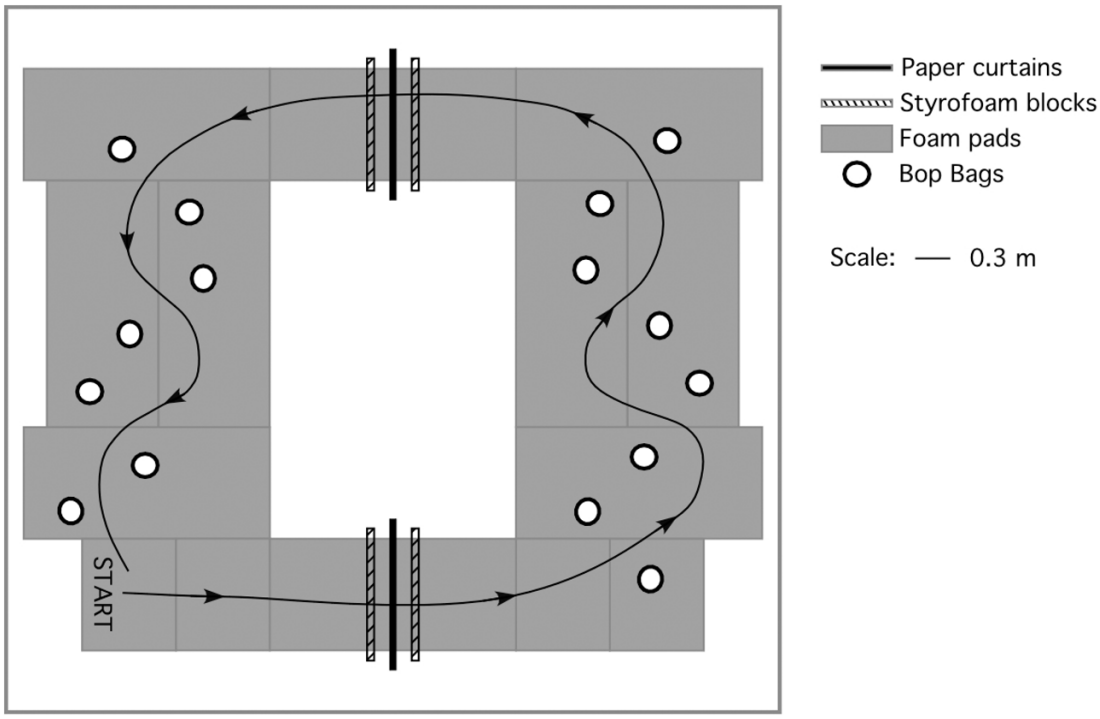

Figure 1.
Plan view of the FMT obstacle course

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Table 1

Descriptive statistics of the number of obstacles touched at each test date. For each trial values given are mean (standard deviation), [median (range)].

Test	Trial	Sham	Single lens	Multiple lenses
Pre-	1	0.6 (0.8) [0 (0 to 2)]	0.7 (0.9) [0 (0 to 2)]	0.6 (0.8) [0 (0 to 2)]
	2	0.9 (0.7) [1 (0 to 2)]	0.5 (0.7) [0 (0 to 2)]	0.5 (0.5) [0 (0 to 1)]
Post-	1	0.5 (0.7) [0 (0 to 2)]	0.1 (0.3) 0 (0 to 1)	0.3 (0.4) [0 (0 to 1)]
	2	0.1 (0.3) [0 (0 to 1)]	0.2 (0.4) [0 (0 to 1)]	0.3 (0.7) [0 (0 to 2)]
Transfer	1	3.9 (1.9) [4 (0 to 8)]	2.9 (2.4) [3 (0 to 8)]	2.2 (2.0) [1.5 (0 to 7)]
	2	2.5 (1.7) [2 (0 to 5)]	1.8 (2.1) [1 (0 to 9)]	2.1 (2.9) [1 (0 to 11)]
Follow-up	1	0.1 (0.3) [0 (0 to 1)]	0.2 (0.4) [0 (0 to 1)]	0.2 (0.4) [0 (0 to 1)]
	2	0.1 (0.3) [0 (0 to 1)]	0.1 (0.3) [0 (0 to 1)]	0.3 (0.5) [0 (0 to 1)]
Retention	1	0.3 (0.5) [0 (0 to 1)]	0.9 (0.9) [1 (0 to 3)]	0.6 (0.7) [0.5 (0 to 2)]
	2	1.1 (1.2) [1 (0 to 3)]	0.6 (0.7) [1 (0 to 2)]	0.5 (1.0) [0 (0 to 3)]

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Table 2

Descriptive statistics of the time (sec) to complete the course at each test date. For each trial values given are mean (standard deviation) [range].

Test	Trial	Sham	Single lens	Multiple lenses
Pre-	1	14.7 (3.2) [10 to 24]	15.8 (2.6) [9.7 to 19.3]	16.8 (3.4) [12.3 to 23.4]
	2	14.1 (3.3) [8.1 to 23.2]	15.1(2.7) [10.7 to 19.4]	15.1 (2.6) [11.8 to 21.3]
Post-	1	13.6 (2.8) [9.6 to 21.0]	15.7 (2.4) [11.5 to 21.0]	15.1 (2.6) [11.8 to 21.3]
	2	13.9 (3.1) [9.5 to 23.0]	15.8 (2.4) [12.0 to 20.0]	15.1 (2.9) [11.6 to 21.2]
Transfer	1	21.4 (5.2) [14.0 to 36.0]	24.7 (6.0) [14.9 to 38.0]	22.7 (6.2) [11.8 to 40.0]
	2	21.0 (5.0) [13.0 to 32.0]	22.4 (5.7) [13.6 to 35.0]	21.8 (6.0) [14.8 to 40.0]
Follow-up	1	14.0 (2.7) [10.0 to 19.0]	16.5 (3.0) [13.0 23.0]	15.7 (3.9) [7.8 to 20.8]
	2	14.0 (2.8) [10.0 to 19.3]	16.5 (3.4) [12.0 to 22.0]	15.1 (3.9) [7.6 to 19.7]
Retention	1	18.7 (3.0) [14.7 to 24.1]	21.2 (4.6) [15.0 to 29.0]	21.4 (5.2) [13.4 to 29.0]
	2	17.3 (4.0) [9.9 to 24.2]	19.6 (4.6) [13.0 to 28.0]	18.9 (5.4) [10.7 to 27.0]